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Cellular Reservoir Flexible Pressure Vessel, Apparatus and Method for Making Same

Earlier Filed Application

The instant application is a continuation-in-part of applicant's prior application filed November 13, 2002 and having serial number 10/294,825 and currently pending, the disclosure of which is specifically incorporated by reference herein.

Field of Invention

The invention pertains to devices for storing gases and fluids under pressure. More particularly, the invention relates to pressure vessels that are formed out of flexible materials and that can be made to conform to a variety of shapes.

Background of the Invention

Typically, pressure vessels capable of containing liquids or gases at significant pressures have involved fixed shape cylinders or spheres formed of high-strength metals such as steel or aluminum. Such pressure vessels, while successful for their designed applications, involve a number of problems. First, such metallic cylinders are relatively heavy compared to the gases or fluids that they contain. Second, pressure cylinders contain all of the gas or liquid in a single space. Should the vessel rupture, the entire vessel is destroyed, often with a violent explosion sending shards of metal in all directions. Third, metallic cylinders have a definite shape and cannot be adapted to fit readily in many space-constrained applications. The present invention involves a number of small cells of an elongated tubular shape linked to

each other by collecting end caps. The result of this design is that the pressure vessel may be readily formed into a variety of useful shapes to accommodate special applications. A pressure vessel of this type can be lightweight, adaptable to a variety of spaces and unusual applications, and is inherently safer in rupture situations.

A particular problem associated with pressure vessels operated at high pressure is the conditions under which they fail. Metallic cylinders are particularly dangerous in this regard as they may fragment suddenly if aged or fatigued from many use cycles, even if equipped with overpressure release devices. The present invention provides for a number of controlled pressure release mechanisms that are easily incorporated into the flexible pressure vessels.

The use of numerous small linked pressure vessels also present problems related to effectively joining such vessels together. The present invention provides for novel manufacturing methods for joining such cells.

Various designs have been developed using elongated tubular shaped vessels, most in the area of radiators and heat exchangers. U.S. Patent No. 6,390,187 issued to *Marechal et al.* discloses a heat exchanger with flexible tubes. The tubes may be made from a plastic material and are designed to carry a heat-exchanging fluid capable of cooperating with an air stream circulating through the exchanger. The invention is intended to describe the method by which the tubes are maintained in parallel rows. The tubes are made from a plastic material and communicate by way of their extremities with two manifolds. The manifolds include collector plates equipped with apertures that thus form a means for holding the tubes in place. The tubes are arranged in rows that are parallel to one another by a distance corresponding to the tube thickness so that the various rows are adjacent in pairs of respective tubes of two consecutive

pairs. The tubes generally exhibit a sinusoidal shape and thus aligned for expanding and contraction so that the tubes may utilize the flexible characteristics and maintain the integrity of the system.

U.S. Patent No. 4,450,902 issued to *Bosne*, is directed to a heat exchanger in particular for an atmospheric cooling tower. The exchanger utilizes synthetic plastic material for the tubes that has one fixed header while the remainder of the exchanger is mounted by suspension to allow for free expansion. A chamber has a heat exchanger with a series of tubes extending throughout the length of chamber. The exchanger comprises a battery of smooth tubes made of a synthetic material. The tubes of the heat exchanger are fixed to the support structure at one of the ends and is freely suspended by a suspension members to allow for expansion and contraction.

U.S. Patent No. 5,158,134, issued to *Mongia et al.,* discloses a fully floating tube bundle. The exchanger comprises a plurality of fluid carrying tubes that is free floating with no direct contact between the end plates or center plate. Thus, the tubes are free to move with respect to the end plates and center plate as to eliminate damage by vibration and temperature changes.

U.S. Patent No. 4,114,683 issued to *Verlinden* describes a flexible tube type fluid-fluid heat exchanger. The exchanger comprises a plurality of flexible synthetic tubes extending in a curved path between a pair of headers. The tubes are connected to headers and are constructed of a flexible plastic material so they may easily conform to the curvature of the wall 11.

U.S. Patent No. 5,651,474 issued to *Callaghan et al* is directed to cryogenic structures that are vessels made of a durable plastic material and are adapted to contain cryogenic materials such as fuel. The structures are made of a fiber network impregnated with a matrix of thermal set plastics and have three tank lobes of a composite plastic reinforced with fibers. The tank lobes may be filament-wound on a rotating mandrel while the fibers are pre-impregnated with resin. Another technique is to heat the tank skins allowing the pre-impregnated fiber layers to fuse together and then cool so as to set up a solid matrix that grips the fibers.

While other variations exist, the above-described designs involving elongated tubular shaped vessels are typical of those encountered in the prior art. It is an objective of the present invention to provide a flexible pressure vessel that is capable of maintaining gasses or liquids at relatively high pressures. It is a further objective to provide this capability in a vessel that is light in weight and that presents a significantly reduced risk of injury in rupture situations. It is a still further objective of the invention to provide a pressure vessel that may be easily adapted to a variety of space constraints. It is yet a further objective to provide a pressure vessel that is durable, easily serviced, and that may be produced inexpensively.

While some of the objectives of the present invention are disclosed in the prior art, none of the inventions found include all of the requirements identified.

Summary of the Invention

(1) A cellular reservoir flexible pressure vessel providing the desired features may be constructed from the following components. A plurality of flexible tubes is provided. Each of

the flexible tubes are formed of resilient material and have an outer surface, an inner surface, a first end and a second end.

First and second end caps are provided. Each of the end caps have a receptacle for either of the first or second ends of each of the flexible tubes, a collecting reservoir, a surrounding outer rim and an outer perimeter perpendicular to the surrounding outer rim. At least one of the first and second end caps have a passageway connecting to the collecting reservoir for connection to either a passageway of another pressure vessel or a valve. Each of the receptacles has a surrounding wall, a base and an orifice penetrating the base and connects the receptacle to either the collecting reservoir or the passageway. The wall has an interior surface. The interior surface is sized and shaped to fit frictionally over the outer surface of one of the flexible tubes at either the first or second ends. The collecting reservoir has an outer surface and connects the base of each of the receptacles to a common space. The common space is either closed or connected to the passageway. The surrounding outer rim extends outwardly from the outer surface of the collecting reservoir for a first predetermined distance along the flexible tubes and serves to constrain the flexible tubes.

Means are provided for securing the first and second end caps to the flexible tubes. A valving means is provided. The valving means is capable of controlling a flow of either a liquid or a gas through the passageway and is attached to a distal end of the passageway. When the flexible tubes are inserted into the receptacles of the end caps and secured thereto, a flexible pressure vessel will be formed capable of containing either a liquid or a gas at high pressure.

(2) In a variant of the invention, the means for securing the first and second end caps to the flexible tubes is selected from the group comprising: radio frequency welding, high-strength adhesive, mechanical fastening and sonic welding.

(3) In another variant of the invention, a protruding rim is provided. The protruding rim is located at the outer perimeter of the first and second end caps and upper and lower receiving notches located above and below the protruding rim. A reinforcing ring is provided. The reinforcing ring has an inner surface, an outer surface and is formed of high-strength material and is sized and shaped to fit tightly about the outer perimeter of the end cap. The reinforcing ring has an upper and lower projecting ribs and a central receiving notch located between the upper and lower projecting ribs. The projecting ribs are sized, shaped and located to fit the upper and lower receiving notches of the end cap. The central receiving notch is sized, shaped and located to fit the protruding rim of the end cap. The reinforcing ring has an aperture. The aperture extends from the inner surface to the outer surface and is sized, shaped and located to accommodate the passageway of the end cap. When the reinforcing ring is located about the outer perimeter of the first and second end caps, the pressure handling capacity of the pressure vessel is increased.

(4) In yet a further variant of the invention, a protruding rim is provided. The protruding rim is located at the outer perimeter of the first and second end caps and upper and lower receiving notches located above and below the protruding rim.

Upper and lower reinforcing rings are provided. Each of the reinforcing rings have an inner surface, an outer surface and are formed of high-strength material and are sized and shaped to fit tightly in either of the upper and lower receiving notches. At least one of the

reinforcing rings has an aperture. The aperture extends from the inner surface to the outer surface and is sized, shaped and located to accommodate the passageway connecting to the collecting reservoir. When the reinforcing rings are located about the outer perimeter of the first and second end caps, the pressure handling capacity of the pressure vessel is increased.

(5) In still a further variant, means are provided for fastening the upper reinforcing ring to the lower reinforcing ring.

(6) In still a further variant of the invention, a protruding rim is provided. The protruding rim is located at the outer perimeter of the first and second end caps. At least one groove located about the outer perimeter above the protruding rim is provided. At least one groove located about the outer perimeter below the protruding rim is provided. Upper and lower reinforcing rings are provided. Each of the reinforcing rings have an inner surface, an outer surface and are formed of high-strength material and are sized and shaped to fit tightly about the outer perimeter on either side of the protruding rim. The reinforcing rings have at least one rib located upon the inner surface thereof, the rib is sized, shaped and located to engage the groove. When the reinforcing rings are located about the outer perimeter of the first and second end caps, the pressure handling capacity of the pressure vessel is increased.

(7) In another variant, means are provided for fastening the upper reinforcing ring to the lower reinforcing ring.

(8) In yet a further variant of the invention, a sintactic foam filler is provided. The foam filler is located within the collecting reservoir of at least one of the first and second end caps. The foam filler has a series of canals through it. Each of the canals connects the orifice of the receptacle to the passageway. An opening in the end cap is provided. The opening

provides means for introduction of the sintactic foam into the end cap. A sealing plug is provided. The sealing plug is sized and shaped to fit sealably into the opening in the end cap. When the syntactic foam is introduced into the end cap, the pressure handling capacity of the pressure vessel is increased.

(9) In still a further variant of the invention, a sintactic foam filler is provided. The foam filler is located within the collecting reservoir of at least one of the first and second end caps. The foam filler is penetrated by a series of flexible microtubes. Each of the microtubes connects the orifice of the receptacle to the passageway. An opening in the end cap is provided. The opening provides means for introduction of the syntactic foam into the end cap. A sealing plug is provided. The sealing plug is sized and shaped to fit sealably into the opening in the end cap. When the microtubes are connected to the orifice of the receptacles in the end cap, the purity of either liquids or gasses stored in the pressure vessel is increased.

(10) In yet a further variant of the invention, an overwrapping of high-strength braiding material is provided. The braiding material extends over the flexible tubes and the first and second end caps. When the flexible pressure vessel is so overwrapped, its pressure-handling capability will be increased.

(11) In still a further variant, hoop winding of the vessel with high-strength materials is provided. The hoop winding extends over the flexible tubes and the first and second end caps. When the flexible pressure vessel is so hoop wound, its pressure-handling capability will be increased.

(12, 13) In another variant, a plastic overcoating is provided. The overcoating further increases the pressure-handling capability of the pressure vessel.

(14) In yet a further variant of the invention, a first flexible blanket is provided. The first blanket has an upper surface, a lower surface and is sized and shaped to cover the pressure vessel and extends outwardly beyond the outer edges thereof. The first blanket is fixedly attached at its lower surface to an upper surface of the pressure vessel. A second flexible blanket is provided. The second blanket has an upper surface, a lower surface and is sized and shaped to cover the pressure vessel and extends outwardly beyond the outer edges. The second blanket is fixedly attached at its upper surface to a lower surface of the pressure vessel. When the first and second flexible blankets are attached to the pressure vessel, the pressure handling capability of the pressure vessel will be increased.

(15) In another variant, heavy duty stitching is used to attach the first blanket to the second blanket. The stitching penetrates the first and second blankets and serves to further reinforce and increase the pressure-handling capabilities of the pressure vessel.

(16) In still another variant, the heavy duty stitching is high pressure hoop and lock braiding.

(17) In still a further variant of the invention, the cross-sectional shape of the outer surface of the flexible tubing is selected from the group comprising: square, triangular, round, hexagonal, ovoid, octagonal and star-shaped.

(18) In yet a further variant of the invention, the cross-sectional shape of the inner surface of the flexible tubing is selected from the group comprising: square, triangle, round, hexagonal, ovoid, octagonal, and star-shaped.

(19) In still a further variant of the invention, the cross-sectional shape of the flexible pressure vessel is selected from the group comprising: square, triangular, round, hexagonal, ovoid, octagonal, pillow-shaped, saddle-shaped, and a flattened mat shape.

(20) In yet a further variant of the invention, each of the receptacles are of a concave form selected from the group comprising: conical, dome-shaped, ellipsoid and stair-stepped.

(21) In a variant, the first and second ends of each of the flexible tubes are sized and shaped to fit sealably into the receptacles.

(22) In still a further variant of the invention, upper and lower reinforcing panels are provided. The reinforcing panels are formed of high-strength woven material and are shaped as a form to cover at least half of a surface area of the pressure vessel with extensions projecting from a perimeter of the form. The reinforcing panels are adhered to an outer surface of the pressure vessel, thereby increasing the pressure handling capability of the pressure vessel.

(23) In a variant, the method of adhesion is selected from the group comprising: high-strength adhesive, sonic welding and RF welding.

(24) In another variant, the woven material is prepregnated with either adhesive or laminating material and subjected to heat and pressure.

(25) An apparatus for fabricating a cellular reservoir flexible pressure vessel may be constructed from the following components. A raw plastic storage and feeding unit is provided. The storage and feeding unit contains a supply of raw plastic. A multi-head extruder is provided. The extruder includes a heating facility and is in communication with the feeding unit. A cooling tank is provided. The cooling tank is located downstream from

the extruder. A power puller is provided. The puller serves to pull a tubing bundle from the cooling tank. Core tubing forming dies are provided. The forming dies form the tubing bundle into a predetermined shape. A binder head is provided. The binder head has an attached binder tank containing liquid binder material. A binder applicator is provided. The binder applicator comprises a secondary forming die and serves to affix the binder material to the tubing bundle. A cutting unit is provided. The cutting unit comprises a laser calibration facility and serves to cut the tubing bundle to a predetermined length. A conveyer facility is provided. The conveyer facility comprises means for positioning a cut tubing bundle. A rotating head and ram is provided. The head comprises a glue head applicator. The glue head applicator attaches to a glue tank. A plurality of preformed end caps are provided. An automated end cap loader is provided. The end cap loader positions the plurality of end caps. An automated end cap installer attached to the automated end cap loader is provided. The installer serves to attach the end caps to the tubing bundle. A high-intensity UV lamp assembly is provided. The lamp assembly serves to cure the glue.

(26) In a variant of the apparatus for fabricating a cellular reservoir flexible pressure vessel, a plurality of reinforcing rings is provided. The reinforcing rings are formed of high-strength material. A reinforcing ring auto loader is provided. A swivel ram is provided. The ram comprises of a ring loading and placement head. The swivel ram is in cooperation with the ring auto loader and serves to press the reinforcing ring onto the pressure vessel.

(27) In another variant of the apparatus for fabricating a cellular reservoir flexible pressure vessel, either a gas or liquid supply tank is provided. An auto loader test head is provided. The test head is adaptable to fittings on the end caps. A cryogenic test unit in

communication with the test head is provided. The test head and the test unit provides means for pressurizing the pressure vessel.

(28) In yet a further variant of the apparatus for fabricating a cellular reservoir flexible pressure vessel, a reinforcing blanket material is provided. A glue spraying mechanism is provided. The mechanism comprises of glue tanks, glue spray heads and glue for attaching the blanket material to the pressure vessel. A blanket material feed mechanism is provided. A press forming tool is provided. The tool is adapted to form the blanket material over the cut tubing bundle and the attached end caps.

(29) In a variant, a high-strength thread is provided. A stitching head is provided. The stitching head is adapted to sew the high-strength thread through the reinforcing blanket material.

(30) In still a further variant of the apparatus for fabricating a cellular reservoir flexible pressure vessel, a high-strength braiding material is provided. A braider is provided. The braider is adapted to position and provide overwrapping of the pressure vessel with the braiding material. A binder spraying mechanism is provided. The spraying mechanism comprises of a binder tank, a binder spray head and binder material.

(31) In yet a further variant of the apparatus for fabricating a cellular reservoir flexible pressure vessel, a high-strength reinforcing ribbon is provided. An automated reinforcing ribbon winding machine is provided. The winding machine comprises of a reinforcing ribbon spool and an auto layout ribbon head. A binder spraying mechanism is provided. The spraying machine comprises of a binder tank, a binder spray head and binder material.

(32) In still a further variant of the apparatus for fabricating a cellular reservoir flexible pressure vessel, means are provided for pulling a series of high tensile strength core wires through orifices in receptacles in the end cap to a passageway in the end cap. Means are provided for injecting sintactic foam through an opening in the end cap. Means are provided for attaching a sealing plug to the opening. Means are provided for removing the core wires from the end cap. When the core wires are removed from the end cap, a series of canals will be formed in the sintactic foam connecting orifices in receptacles in the end cap to the passageway.

(33) In yet a further variant of the apparatus for fabricating a cellular reservoir flexible pressure vessel, means are provided for attaching a series of flexible microtubes to orifices in receptacles in the end cap to a passageway in the end cap. Means are provided for injecting sintactic foam through an opening in the end cap. Means are provided for attaching a sealing plug to the opening. Means are provided for removing the core wires from the end cap. When the microtubes are connected to the passageway, the pressure vessel will provide an ultra clean environment for either liquids or gasses.

(34) In still a further variant of the apparatus for fabricating a cellular reservoir flexible pressure vessel, means are provided for forming a concave receptacle having a shape selected from the group comprising: conical, dome-shaped, ellipsoid and stair-stepped.

(35) In a variant, means are provided for forming the first and second ends of each of the flexible tubes to fit sealably into the receptacles.

(36) In yet a further variant of the apparatus for fabricating a cellular reservoir flexible pressure vessel, means are provided for forming upper and lower reinforcing panels. The

reinforcing panels are formed of high-strength woven material and are shaped as a form to cover at least half of a surface area of the pressure vessel with extensions projecting from a perimeter from the form. Means are provided for adhering the reinforcing panel to the outer surface of the pressure vessel, thereby increasing the pressure handling capability of the pressure vessel.

(37) In a variant of the apparatus for fabricating a cellular reservoir flexible pressure vessel, the method of adhesion is selected from the group comprising: high-strength adhesive, sonic welding and RF welding.

(38) In another variant of the apparatus for fabricating a cellular reservoir flexible pressure vessel, the woven material is prepregnated with either adhesive or laminating material and subjected to heat and pressure.

(53) In yet another variant of the invention, the cellular reservoir flexible pressure vessel, has a first pressure relief device. The first pressure relief device is located on an inner surface of either the first or second end caps and includes a reduction in thickness of the end cap at a predetermined location. When the pressure vessel is subjected to an overpressure condition, it will fail at the predetermined location.

(54) In still another variant of the invention, the first pressure relief device has an indentation in the inner surface of either the first or second end caps. The indentation has side walls angled inwardly from the inner surface.

(55) In still a further variant of the invention, the cellular reservoir flexible pressure vessel has a second pressure relief device. The second pressure relief device is located on an outer surface of the flexible pressure vessel and has at least one projecting member. The

projecting member is sized and shaped to penetrate the high-strength braiding material at a predetermined location. When the high-strength braiding material is penetrated by the projecting member and the flexible pressure vessel is subjected to an overpressure condition, the vessel will fail at the predetermined location.

(56) In an additional variant, the projecting member is removably attached to the outer surface of the flexible pressure vessel.

(57) In another variant, the cellular reservoir flexible pressure vessel has a second pressure relief device. The second pressure relief device is located on an outer surface of the flexible pressure vessel and has at least one projecting member. The projecting member is sized and shaped to penetrate the high-strength material at a predetermined location. When the high-strength material is penetrated by the projecting member and the flexible pressure vessel is subjected to an overpressure condition, the vessel will fail at the predetermined location.

(58) In a further variant, the projecting member is removably attached to the outer surface of the flexible pressure vessel.

(59) In still a further variant, the cellular reservoir flexible pressure vessel has a second pressure relief device. The second pressure relief device is located on an outer surface of the flexible pressure vessel and has at least one projecting member. The projecting member is sized and shaped to penetrate either the first or second flexible blankets at a predetermined location. When either the first or second flexible blanket is penetrated by the projecting member and the flexible pressure vessel is subjected to an overpressure condition, the vessel will fail at the predetermined location.

(60) In another variant of the invention, the projecting member is removably attached to the outer surface of the flexible pressure vessel.

(61) In an additional variant of the invention, the ovoid flexible pressure vessel has a second pressure relief device. The second pressure relief device is located on the outer surface of the flexible pressure vessel and has at least one projecting member. The projecting member is sized and shaped to penetrate either the upper or lower reinforcing panels at a predetermined location. When either the upper or lower reinforcing panel is penetrated by the projecting member and the flexible pressure vessel is subjected to an overpressure condition, the vessel will fail at the predetermined location.

(62) In a further variant of the invention, the projecting member is removably attached to the outer surface of the flexible pressure vessel.

(63) In still a further variant of the invention, the cellular reservoir flexible pressure vessel has a third pressure relief device. The third pressure relief device has a weakened section of the passageway. When the flexible pressure vessel is subjected to an overpressure condition, the flexible pressure vessel will fail at the weakened section of the passageway.

(64) In another variant, the weakened section of the passageway has a smaller cross-sectional area than a balance of the passageway.

(65) In an additional variant, the cellular reservoir flexible pressure vessel has high-strength braiding material wound about the passageway, thereby providing additional resistance to pressure for the flexible pressure vessel.

(66) In a further variant, the cellular reservoir flexible pressure vessel has a fourth pressure relief device. The fourth pressure relief device has either a weakening or an absence

of high-strength braiding material at a predetermined location along the passageway. When the flexible pressure vessel is subjected to an overpressure condition, the flexible pressure vessel will fail at the predetermined location along the passageway.

(67) In still a further variant, the cellular reservoir flexible pressure vessel has hoop winding about the passageway, thereby providing additional resistance to pressure to the flexible pressure vessel.

(68) In another variant of the invention, the cellular reservoir flexible pressure vessel has a fifth pressure relief device. The fifth pressure relief device has either a weakening or an absence of hoop winding at a predetermined location along the passageway. When the flexible pressure vessel is subjected to an overpressure condition, the pressure vessel will fail at the predetermined location along the passageway.

(69) In an additional variant, the cellular reservoir flexible pressure vessel has either a weakening or a spreading of fibers in the high-strength braiding material at a predetermined location. The predetermined location is above an outer surface of the pressure vessel. When the high-strength braiding material has the fibers weakened or spread in the predetermined location and the pressure vessel is subjected to an overpressure condition, the pressure vessel will fail at the predetermined location.

(70) In a further variant, the cellular reservoir flexible pressure vessel has either a weakening or a spreading of fibers in the high-strength material at a predetermined location. The predetermined location is above an outer surface of the pressure vessel. When the high-strength material has the fibers weakened or spread in the predetermined location and the

pressure vessel is subjected to an overpressure condition, the pressure vessel will fail at the predetermined location.

(71) In still a further variant, the cellular reservoir flexible pressure vessel has either a weakening or a spreading of fibers in either of the first flexible blanket and the second flexible blanket at a predetermined location. The predetermined location is above an outer surface of the pressure vessel. When either of the first flexible blanket and the second flexible blanket has the fibers weakened or spread in the predetermined location and the pressure vessel is subjected to an overpressure condition, the pressure vessel will fail at the predetermined location.

(72) In another variant of the invention, the cellular reservoir flexible pressure vessel has either a weakening or a spreading of fibers in either the upper or lower reinforcing panels at a predetermined location. The predetermined location is above the outer surface of the pressure vessel. When either of the upper or lower reinforcing panels has the fibers weakened or spread in the predetermined location and the pressure vessel is subjected to an overpressure condition, the pressure vessel will fail at the predetermined location.

(73) In an additional variant, the connection to either a passageway of another vessel or a valve further has a capillary tube. The capillary tube has a proximate end and a distal end and is formed of resilient material and sized and shaped to fit slidably within the passageway. High-strength braiding material is provided. The braiding material is located about the capillary tube and extends along the capillary tube to within a first predetermined distance from the proximate end. The proximate end of the braiding covered capillary tube is inserted into the passageway and is either radio frequency welded or secured with adhesive to it.

When the proximate end of the capillary tube is either welded or secured with adhesive within the passageway, it will be permanently attached to it.

(74) In a further variant of the invention, an apparatus for modifying reinforcing panel material is provided. The apparatus has means for supporting a supply roll of flexible blanket material. Means for moving the flexible blanket material from the supply roll to a work area is provided. Means for tensioning the flexible blanket material in the work area is also provided. At least one separating member, which is sized and shaped to penetrate and separate fibers of the flexible blanket material is further provided.

Also provided is a means for moving the separating member into the tensioned flexible blanket material at a predetermined location in the material, thereby either weakening and separating the fibers. Means for retracting the separating member from the tensioned flexible blanket material is provided. Means for moving the flexible blanket material from work area to a storage area is provided. The flexible blanket material will have either a weakened or separated fibers in the predetermined location prior to application to the pressure vessel.

(75) In still a further variant of the invention, an apparatus for modifying reinforcing panel material is provided. The apparatus has means for supporting a supply roll of reinforcing panel material. Means for moving the reinforcing panel material from the supply roll to a work area is provided. Means for tensioning the reinforcing panel material in the work area is provided. At least one separating member is provided. The separating member is sized and shaped to penetrate and separate fibers of the reinforcing panel material. Also provided are means for moving the separating member into the tensioned reinforcing panel material at a predetermined location in the material, thereby either weakening or separating

the fibers. Means for retracting the separating member from the tensioned reinforcing panel material is provided. Means for moving the reinforcing panel material from work area to a storage area is provided. The reinforcing panel material will have either weakened or separated fibers in the predetermined location prior to application to the pressure vessel.

(76) In another variant, a method for making the cellular reservoir flexible pressure vessel is provided. The method has the following steps: providing a supply roll of flexible blanket material; supporting the supply roll; moving the flexible blanket material from the supply roll to a work area; tensioning the flexible blanket material in the work area; providing at least one separating member, where the member is sized and shaped to penetrate and separate fibers of the flexible blanket material; moving the separating member into the tensioned flexible blanket material at a predetermined location in the material, thereby either weakening or separating the fibers; retracting the separating member from the tensioned flexible blanket material; moving the flexible blanket material from work area to a storage area. The flexible blanket material will have either weakened or separated fibers in the predetermined location prior to application to the pressure vessel.

(77) In a final variant, a method for making the cellular reservoir flexible pressure vessel has the following steps: providing a supply roll of reinforcing panel material; providing means for supporting the supply roll; moving the reinforcing panel material from the supply roll to a work area; tensioning the reinforcing panel material in the work area; providing at least one separating member, where the member is sized and shaped to penetrate and separate fibers of the reinforcing panel material; moving the separating member into the tensioned reinforcing panel material at a predetermined location in the material, thereby either

weakening or separating the fibers; retracting the separating member from the tensioned reinforcing panel material; moving the reinforcing panel material from work area to a storage area. The reinforcing panel material will have either weakened or separated fibers in the predetermined location prior to application to the pressure vessel.

Description of the Drawings

Figure 1 is a plan view of a first embodiment of the invention illustrating cellular reservoir cells, first and second end caps, a connecting passageways and a valve;

Figure 2 is a cross-sectional view of the **Figure 1** embodiment taken along the line **2-2**;

Figure 2A is an end cross-sectional view of the **Figure 1** embodiment taken along the line **2A-2A**;

Figure 3 is an end view of the **Figure 1** embodiment taken along the line **3-3** illustrating a first embodiment of a reinforcing ring, an aperture in the ring and a cross-section of the ring in partial cutaway;

Figure 3A is a side elevational view of the **Figure 1** embodiment, illustrating a first embodiment of upper and lower reinforcing rings;

Figure 4 is a partial cross-sectional view of the **Figure 3A** embodiment taken along the line **4-4**;

Figure 5 is a partial cross-sectional view of the **Figure 3A** embodiment illustrating a means for fastening the upper and lower reinforcing rings together;

Figure 6 is a partial cross-sectional view of a second embodiment of upper and lower reinforcing rings illustrating grooves and ribs for attaching the rings;

Figure 7 is a partial cross-sectional view of a third embodiment of upper and lower reinforcing rings illustrating grooves and ribs for attaching the rings and means for attaching the rings together;

Figure 8 is a cross-sectional view of an end cap illustrating means for introducing sintactic foam into the end cap and wires for forming canals through the foam;

Figure 9 is a cross-sectional view of an end cap illustrating microtubes connecting the receptacles to the passageway and a sealing plug for closing the end cap after introduction of the syntactic foam;

Figure 10 is a side elevational view of the **Figure 1** embodiment illustrating an overwrapping of high-strength braiding material;

Figure 11 is a side elevational view of the **Figure 1** embodiment illustrating hoop winding;

Figure 12 is a partial cross-sectional view of the **Figure 1** embodiment illustrating a plastic overcoating;

Figure 13 cross-sectional view of the **Figure 1** embodiment illustrating flexible blankets attached to the pressure vessel;

Figure 14 is a plan view of the **Figure 1** embodiment illustrating high-strength stitching of the flexible blankets;

Figure 15A is a cross-sectional view of a cellular reservoir tube having a hexagonal external cross-section;

Figure 15B is a cross-sectional view of a cellular reservoir tube having a square external cross-section;

Figure 15C is a cross-sectional view of a cellular reservoir tube having a equilateral triangular external cross-section;

Figure 15D is a cross-sectional view of a cellular reservoir tube having an oval external cross-section;

Figure 15E is a cross-sectional view of a cellular reservoir tube having a right triangular external cross-section;

Figure 15F is a cross-sectional view of a cellular reservoir tube having a round external cross-section;

Figure 15G is a cross-sectional view of a cellular reservoir tube having a octagonal external cross-section;

Figure 15H is a cross-sectional view of a cellular reservoir tube having a star-shaped external cross-section;

Figure 16A is a cross-sectional view of a cellular reservoir tube having a hexagonal internal cross-section;

Figure 16B is a cross-sectional view of a cellular reservoir tube having a square internal cross-section;

Figure 16C is a cross-sectional view of a cellular reservoir tube having a equilateral tringular internal cross-section;

Figure 16D is a cross-sectional view of a cellular reservoir tube having an oval internal cross-section;

Figure 16E is a cross-sectional view of a cellular reservoir tube having a right triangular internal cross-section;

Figure 16F is a cross-sectional view of a cellular reservoir tube having a round internal cross-section;

Figure 16G is a cross-sectional view of a cellular reservoir tube having a octagonal internal cross-section;

Figure 16H is a cross-sectional view of a cellular reservoir tube having a star-shaped internal cross-section;

Figure 17A is a cross-sectional view of a cellular reservoir flexible pressure vessel having a hexagonal shape;

Figure 17B is a cross-sectional view of a cellular reservoir flexible pressure vessel having a square shape;

Figure 17C is a cross-sectional view of a cellular reservoir flexible pressure vessel having an equilateral triangular shape;

Figure 17D is a cross-sectional view of a cellular reservoir flexible pressure vessel having an oval shape;

Figure 17E is a cross-sectional view of a cellular reservoir flexible pressure vessel having an airfoil shape;

Figure 17F is a cross-sectional view of a cellular reservoir flexible pressure vessel having a right triangular shape;

Figure 17G is a cross-sectional view of a cellular reservoir flexible pressure vessel having a round shape;

Figure 17H is a cross-sectional view of a cellular reservoir flexible pressure vessel having a octagonal shape;

Figure 17I is a cross-sectional view of a cellular reservoir flexible pressure vessel having a saddle shape;

Figure 17J is a cross-sectional view of a cellular reservoir flexible pressure vessel having a flat mat shape;

Figure 18A is a cross-sectional view of a receptacle and fitting square-shaped flexible tube end;

Figure 18B is a cross-sectional view of a receptacle and fitting cone-shaped flexible tube end;

Figure 18C is a cross-sectional view of a receptacle and fitting hemi-spherical-shaped flexible tube end;

Figure 18D is a cross-sectional view of a receptacle and fitting step-shaped flexible tube end;

Figure 18E is a cross-sectional view of a receptacle and fitting bullet-shaped flexible tube end;

Figure 19 is a side elevational view of the **Figure 1** embodiment enclosed in upper and lower reinforcing panels;

Figure 20 is a plan view of the **Figure 1** embodiment on upper and lower reinforcing panels prior to attachment;

Figure 21 is a side elevational view of an apparatus for fabricating flexible tubes for a cellular reservoir flexible pressure vessel;

Figure 22 is a side elevational view of an apparatus for attaching the end caps to the flexible tubes;

Figure 23 is a side elevational view of an apparatus for curing the adhesive for the flexible tubes and attaching the reinforcing rings;

Figure 24 is a side elevational view of apparatus for filling the vessel with cryogenic liquid or gas, attaching high-strength blanket material and stitching high-strength thread through the reinforcing blanket material;

Figure 25 is a side elevational view of an apparatus for overwrapping of the pressure vessel with high-strength braiding material;

Figure 26 is a side elevational view of an apparatus for hoop winding reinforcing ribbon onto the pressure vessel;

Figure 27 is a side cross-sectional view of an apparatus for pulling wires into the end cap prior to injection of syntactic foam to leave canals;

Figure 28 is a side cross-sectional view of an apparatus for pulling microtubes into the end cap prior to injection of syntactic foam;

Figure 29 is a detailed side cross-sectional view of an apparatus for forming a concave receptacle having a dome shape;

Figure 29A is a side cross-sectional view of an apparatus for a series of concave receptacles having a dome shape;

Figure 30 is a side cross-sectional view of an apparatus for forming the first and second ends of each of said flexible tubes to fit sealably into said receptacles;

Figure 31 is a perspective view of an apparatus for forming reinforcing panels;

Figure 32 is a perspective view of an apparatus for applying adhesive to a reinforcing panel;

Figure 33 is a plan view of an embodiment of the invention illustrating a first pressure relief device located on an inner surface of an end cap;

Figure 34 is a cross-sectional view of the **Figure 33** embodiment taken along the line **34-34**, illustrating the first pressure relief device on the inner surface of the end cap;

Figure 35 is a plan view of an embodiment of the invention illustrating a second pressure relief device located on an outer surface of an end cap;

Figure 36 is a cross sectional view of the **Figure 35** embodiment of the invention taken along the line **36-36** illustrating the second pressure relief device that has at least one projecting member;

Figure 37 is a plan view of an embodiment of the invention illustrating penetration of the second pressure relief device through the high strength braiding material at a predetermined location;

Figure 38 is a plan view of the **Figure 35** embodiment illustrating a second pressure relief device which is removably attached;

Figure 39 is a cross-sectional view of the **Figure 38** embodiment taken along the line **39-39**;

Figure 40 is a side elevational view of an apparatus for modifying flexible blanket material and for modifying reinforcing panel material;

Figure 40A is perspective view of the **Figure 40** apparatus illustrating the modified fabric or blanket material;

Figure 41 is a plan view of a reinforcing panel with either a weakening or spreading of fibers at a predetermined location;

Figure 42 is a partial detail view of a reinforcing panel or high strength braiding material with either a weakening or spreading of fibers at a predetermined location;

Figure 43 is a cross-sectional view of an embodiment illustrating a third pressure relief device with a weakened section of the passageway;

Figure 44 is a partial detailed view of the **Figure 43** embodiment taken along the line **44-44** illustrating the third pressure relief device;

Figure 45 is a cross-sectional view of an embodiment illustrating the connection of a capillary tube to a passageway and to an end cap prior to insertion and welding;

Figure 46 is a cross-sectional view of the **Figure 45** embodiment illustrating attachment of the capillary tube to the passageway and end cap;

Figure 47 is a plan view of the **Figure 33** embodiment illustrating the weakening or spreading of fibers in the flexible blanket at predetermined location;

Figure 48 is a cross-sectional view of the **Figure 47** embodiment illustrating the a weakening or spreading of fibers in the flexible blanket at predetermined location;

Figure 49 is a cross-sectional view of an embodiment with high strength braiding material wound about the passageway providing additional resistance to pressure for the pressure vessel;

Figure 50 is a cross-sectional view of the **Figure 49** embodiment illustrating a fourth pressure relief device that has either an absence or a weakening of high strength braiding material at a predetermined location on the passageway;

Figure 51 is a cross-sectional view of an embodiment with hoop winding about the passageway providing additional resistance to pressure for the pressure vessel; and

Figure 52 is a cross-sectional view of the **Figure 51** embodiment illustrating a fourth pressure relief device that has either an absence or a weakening of hoop winding at a predetermined location on the passageway.

Detailed Description of the Preferred Embodiment

(1) A cellular reservoir flexible pressure vessel **10** providing the desired features, as shown in **Figures 1, 2** and **2A**, may be constructed from the following components. A plurality of flexible tubes **15** is provided. Each of the flexible tubes **15** are formed of resilient material **20** and has an outer surface **25**, an inner surface **30**, a first end **35** and a second end **40**.

First **45** and second **50** end caps are provided. Each of the end caps **45, 50** has a receptacle **55** for either of the first **35** or second **40** ends of each of the flexible tubes **15**, a collecting reservoir **70**, a surrounding outer rim **75** and an outer perimeter **80** perpendicular to the surrounding outer rim **75**. At least one of the first **45** and second **50** end caps has a passageway **85** connecting to the collecting reservoir **70** as a connection **88** to either a passageway **85** of another pressure vessel **10** or a valve **90**. Each of the receptacles **55** has a surrounding wall **95**, a base **100** and an orifice **105** penetrating the base **100**. The orifice **105** connects the receptacle **55** to either the collecting reservoir **70** or the passageway **85**. The wall **95** has an interior surface **110**. The interior surface **110** is sized and shaped to fit frictionally over the outer surface **25** of one of the flexible tubes **15** at either the first **35** or second **40** ends. The collecting reservoir **70** has an outer surface **115** and connects the base **100** of each of the receptacles **55** to a common space **120**. The common space **120** is either closed or

connected to the passageway **85**. The surrounding outer rim **75** extends outwardly from the outer surface **115** of the collecting reservoir **70** for a first predetermined distance **125** along the flexible tubes **15** and serves to constrain the flexible tubes **15**.

Means **130** are provided for securing the first **45** and second **50** end caps to the flexible tubes **15**. A valving means **135** is provided. The valving means **135** is capable of controlling a flow of either a liquid or a gas through the passageway **85** and is attached to a distal end **150** of the passageway **85**. When the flexible tubes **15** are inserted into the receptacles **55** of the end caps **45, 50** and secured thereto, a flexible pressure vessel **10** will be formed capable of containing either a liquid or a gas at high pressure.

(2) In a variant of the invention, as shown in **Figures 1-2**, the means **130** for securing the first **45** and second **50** end caps to the flexible tubes **15** is selected from the group comprising: radio frequency welding, high-strength adhesive, mechanical fastening and sonic welding.

(3) In another variant of the invention, as shown in **Figure 3**, a protruding rim **180** is provided. The protruding rim **180** is located at the outer perimeter **80** of the first **45** and second **50** end caps and upper **185** and lower **190** receiving notches located above and below the protruding rim **180**. A reinforcing ring **195** is provided. The reinforcing ring **195** has an inner surface **200**, an outer surface **205** and is formed of high-strength material **206.** The reinforcing ring **195** is sized and shaped to fit tightly about the outer perimeter **80** of the end caps **45, 50**. The reinforcing ring **195** has an upper **210** and lower **215** projecting ribs and a central receiving notch **220** located between the upper **210** and lower **215** projecting ribs. The projecting ribs **210, 215** are sized, shaped and located to fit the upper **185** and lower **190**

receiving notches of the end caps **45, 50**. The central receiving notch **220** is sized, shaped and located to fit the protruding rim **180** of the end caps **45, 50**. The reinforcing ring **195** has an aperture **225**. The aperture **225** extends from the inner surface **200** to the outer surface **205** and is sized, shaped and located to accommodate the passageway **85** of the end caps **45, 50**. When the reinforcing ring **195** is located about the outer perimeter **80** of the first **45** and second **50** end caps, the pressure handling capacity of the pressure vessel **10** is increased.

(4) In yet a further variant of the invention, as shown in **Figure 3A** and **Figure 4**, a protruding rim **180** is provided. The protruding rim **180** is located at the outer perimeter **80** of the first **45** and second **50** end caps. Upper **185** and lower **190** receiving notches are provided. The upper **185** and lower **190** receiving notches are located above and below the protruding rim **180**.

Upper **230** and lower **235** reinforcing rings are provided. Each of the reinforcing rings **230, 235** has an inner surface **240**, an outer surface **245** and is formed of high-strength material **246**. The upper **230** and lower **235** reinforcing rings are sized and shaped to fit tightly in either of the upper **185** and lower **190** receiving notches. At least one of the reinforcing rings **230, 235** has an aperture **250**. The aperture **250** extends from the inner surface **240** to the outer surface **245** and is sized, shaped and located to accommodate the passageway **85** connecting to the collecting reservoir **70**. When the reinforcing rings **230, 235** are located about the outer perimeter **80** of the first **45** and second **50** end caps, the pressure handling capacity of the pressure vessel **10** is increased.

(5) In another variant of the invention, as shown in **Figure 5**, means **255** are provided for fastening the upper reinforcing ring **230** to the lower reinforcing ring **235**.

(6) In still a further variant of the invention, as shown in **Figure 6**, a protruding rim **180** is provided. The protruding rim **180** is located at the outer perimeter **80** of the first **45** and second **50** end caps. At least one groove **260** located about the outer perimeter **80** above the protruding rim **180** is provided. At least one groove **260** located about the outer perimeter **80** below the protruding rim **180** is provided. Upper **230** and lower **235** reinforcing rings are provided. Each of the reinforcing rings **230, 235** has an inner surface **240**, an outer surface **245** and is formed of high-strength material **246**. Each of the upper **230** and lower **235** reinforcing rings is sized and shaped to fit tightly about the outer perimeter **80** on either side of the protruding rim **180**. Each of the reinforcing rings **230, 235** has at least one rib **265** located upon the inner surface **240** thereof. The rib **265** is sized, shaped and located to engage the groove **260**. When the reinforcing rings **230, 235** are located about the outer perimeter **80** of the first **45** and second **50** end caps, the pressure handling capacity of the pressure vessel **10** is increased.

(7) In another variant of the invention, as shown in **Figure 7**, means **255** are provided for fastening the upper reinforcing ring **230** to the lower reinforcing ring **235**.

(8) In yet a further variant of the invention, as shown in **Figure 8**, a sintactic foam filler **270** is provided. The foam filler **270** is located within the collecting reservoir **70** of at least one of the first **45** and second **50** end caps. The foam filler **270** has a series of canals **275** through it. Each of the canals **275** connects the orifice **105** of the receptacle **55** to the passageway **85**. An opening **285** in the end caps **45, 50** is provided. The opening **285** provides means **286** for introduction of the foam filler **270** into the end caps **45, 50**. A sealing plug **290** is provided. The sealing plug **290** is sized and shaped to fit sealably into the opening

285 in the end caps **45, 50**. When the foam filler **270** is introduced into the end caps **45, 50**, the pressure handling capacity of the pressure vessel **10** is increased.

(9) In still a further variant of the invention, as shown in **Figure 9**, a sintactic foam filler **270** is provided. The foam filler **270** is located within the collecting reservoir **70** of at least one of the first **45** and second **50** end caps. The foam filler **270** is penetrated by a series of flexible microtubes **291**. Each of the microtubes **291** connects the orifice **105** of the receptacle **55** to the passageway **85**. An opening **285** in the end caps **45, 50** is provided. The opening **285** provides means **286** for introduction of the sintactic foam **270** into the end caps **45, 50**. A sealing plug **290** is provided. The sealing plug **290** is sized and shaped to fit sealably into the opening **285** in the end caps **45, 50**. When the microtubes **291** are connected to the orifices **105** of the receptacles **55** in the end caps **45, 50**, the purity of either liquids or gasses stored in the pressure vessel **10** is increased.

(10) In yet a further variant of the invention, as shown in **Figure 10**, an overwrapping of high-strength braiding material **295** is provided. The braiding material **295** extends over the flexible tubes **15** and the first **45** and second **50** end caps. When the flexible pressure vessel **10** is so overwrapped, its pressure-handling capability will be increased.

(11) In still a further variant of the invention, as shown in **Figure 11**, a hoop winding **305** with high-strength materials **306** is provided. The hoop winding **305** extends over the flexible tubes **15** and the first **45** and second **50** end caps. When the flexible pressure vessel **10** is so hoop wound, its pressure-handling capability will be increased.

(12) In another variant, as shown in **Figure 12**, a plastic overcoating **300** is provided. The overcoating **300** further increases the pressure-handling capability of the pressure vessel **10**.

(13) In another variant, as shown in **Figure 12**, a plastic overcoating **302** is provided. The overcoating **302** further increases the pressure-handling capability of the pressure vessel **10**.

(14) In yet a further variant of the invention, as shown in **Figure 13**, a first flexible blanket **310** is provided. The first blanket **310** has an upper surface **315**, a lower surface **320** and is sized and shaped to cover the pressure vessel **10**. The first flexible blanket **310** extends outwardly beyond the outer edges **325** thereof. The first blanket **310** is fixedly attached at its lower surface **320** to an upper surface **330** of the pressure vessel **10**. A second flexible blanket **335** is provided. The second blanket **335** has an upper surface **340**, a lower surface **345** and is sized and shaped to cover the pressure vessel **10**. The second flexible blanket **335** extends outwardly beyond the outer edges **326** thereof. The second blanket **335** is fixedly attached at its upper surface **340** to a lower surface **355** of the pressure vessel **10**. When the first **310** and second **335** flexible blankets are attached to the pressure vessel **10**, the pressure handling capability of the pressure vessel **10** will be increased.

(15) In another variant, as shown in **Figure 14**, heavy duty stitching **360** is used to attach the first blanket **310** to the second **335** blanket. The stitching **360** penetrates the first **310** and second blanket **335** and serves to further reinforce and increase the pressure-handling capabilities of the pressure vessel **10**.

(16) In still another variant, as shown in **Figure 14**, the heavy duty stitching **360** is high pressure hoop and lock braiding **380**.

(17) In still a further variant of the invention, as shown in **Figure 15A, Figure 15B, Figure 15C, Figure 15D, Figure 15E, Figure 15F, Figure 15G and Figure 15H**, the cross-sectional shape **385** of the outer surface **25** of the flexible tubing **15** is selected from the group comprising: square **390**, triangular **395**, round **400**, hexagonal **405**, ovoid **410**, octagonal **415** and star-shaped **420**.

(18) In yet a further variant of the invention, as shown in **Figure 16A, Figure 16B, Figure 16C, Figure 16D, Figure 16E, Figure 16F, Figure 16G** and **Figure 16H**, the cross-sectional shape **425** of the inner surface **30** of the flexible tubing **15** is selected from the group comprising: square **390**, triangle **395**, round **400**, hexagonal **405**, ovoid **410**, octagonal **415**, and star-shaped **420**.

(19) In still a further variant of the invention, as shown in **Figure 17A, Figure 17B, Figure 17C, Figure 17D, Figure 17E, Figure 17F, Figure 17G, Figure 17H, Figure 17I** and **Figure 17J**, the cross-sectional shape **430** of the flexible pressure vessel **10** is selected from the group comprising: square **390**, triangular **395**, round **400**, hexagonal **405**, ovoid **410**, octagonal **415**, pillow-shaped **470**, saddle-shaped **475**, and a flattened mat shape **480**.

(20) In yet a further variant of the invention, as shown in **Figure 18A, Figure 18B, Figure 18C, Figure 18D** and **Figure 18E**, each of the receptacles **55** are of a concave form **485** selected from the group comprising: conical **490**, dome-shaped **495**, ellipsoid **500** and stair-stepped **505**.

(21) In a variant, as shown in **Figure 18A**, **Figure 18B**, **Figure 18C**, **Figure 18D** and **Figure 18E**, the first **35** and second **40** ends of each of the flexible tubes **15** are sized and shaped to fit sealably into the receptacles **55**.

(22) In still a further variant of the invention, as shown in **Figure 19** and **Figure 20**, upper **510** and lower **515** reinforcing panels are provided. The reinforcing panels **510, 515** are formed of high-strength woven material **520** and are shaped as a form **525** to cover at least half of a surface area **526** of the pressure vessel **10** with extensions **530** projecting from a perimeter **535** of the form **525**. The reinforcing panels **510, 515** are joined to the outer surface **536** of the pressure vessel **10**, thereby increasing the pressure handling capability of the pressure vessel **10**.

(23) In a variant, the method of adhesion is selected from the group comprising: high-strength adhesive, sonic welding and RF welding.

(24) In another variant, as shown in **Figure 20**, the woven material **520** is prepregnated with either adhesive or laminating material and subjected to heat and pressure.

(25) An apparatus for fabricating a cellular reservoir flexible pressure vessel **10** may be constructed, as shown in **Figure 21**, **Figure 22** and **Figure 23**, from the following components. A raw plastic storage and feeding unit **580** is provided. The storage and feeding unit **580** contains a supply of raw plastic **585**. A multi-head extruder **590** is provided. The extruder **590** includes a heating facility **595** and is in communication with the feeding unit **580**. A cooling tank **600** is provided. The cooling tank **600** is located downstream from the extruder **590**. A power puller **605** is provided. The puller **605** serves to pull a tubing bundle **610** from the cooling tank **600**. Core tubing forming dies **615** are provided. The forming dies

615 form the tubing bundle **610** into a predetermined shape **616**. A binder head **620** is provided. The binder head **620** has an attached binder tank **625** containing liquid binder material **630**. A binder applicator **635** is provided. The binder applicator **635** comprises a secondary forming die **640** and serves to affix the binder material **630** to the tubing bundle **610**. A cutting unit **645** is provided. The cutting unit **645** comprises a laser calibration facility **650** and serves to cut the tubing bundle **610** to a predetermined length **655**. A conveyer facility **660** is provided. The conveyer facility **660** comprises means **665** for positioning a cut tubing bundle **610**. A rotating head and ram **670** is provided. The head **670** comprises a glue head applicator **675**. The glue head applicator **675** attaches to a glue tank **680**. A plurality of preformed end caps **45, 50** are provided. An automated end cap loader **690** is provided. The end cap loader **690** positions the plurality of end caps **45, 50**. An automated end cap installer **691** attached to the automated end cap loader **690** is provided. The installer **691** serves to attach the end caps **45, 50** to the tubing bundle **610**. A high-intensity UV lamp assembly **695** is provided. The lamp assembly **695** serves to cure the glue **700**.

(26) In a variant of the apparatus for fabricating a cellular reservoir flexible pressure vessel **10**, as shown in **Figure 23**, a plurality of reinforcing rings **195** is provided. The reinforcing rings **195** are formed of high-strength material **206**. A reinforcing ring auto loader **710** is provided. A swivel ram **715** is provided. The ram **715** comprises of a ring loading and placement head **720**. The swivel ram **715** is in cooperation with the ring auto loader **710** and serves to press the reinforcing ring **195** onto the pressure vessel **10**.

(27) In another variant of the apparatus for fabricating a cellular reservoir flexible pressure vessel **10**, as shown in **Figure 24**, either a gas or liquid supply tank **730** is provided.

An auto loader test head **735** is provided. The test head **735** is adaptable to fittings **736** on the end caps **45, 50**. A cryogenic test unit **740** in communication with the test head **735** is provided. The test head **735** and the test unit **740** provides means **745** for pressurizing the pressure vessel **10**.

(28) In yet a further variant of the apparatus for fabricating a cellular reservoir flexible pressure vessel **10**, as shown in **Figure 24**, reinforcing blanket material **750** is provided. A glue spraying mechanism **755** is provided. The mechanism **755** comprises glue tanks **760**, glue spray heads **765** and glue **766** for attaching the blanket material **750** to the pressure vessel **10**. A blanket material feed mechanism **775** is provided. A press forming tool **780** is provided. The tool **780** is adapted to form the blanket material **750** over the cut tubing bundle **610** and the attached end caps **45, 50**.

(29) In a variant, as shown in **Figure 24**, a high-strength thread **785** is provided. A stitching head **790** is provided. The stitching head **790** is adapted to sew the high-strength thread **785** through the reinforcing blanket material **750**.

(30) In still a further variant of the apparatus for fabricating a cellular reservoir flexible pressure vessel **10**, as shown in **Figure 25**, a high-strength braiding material **795** is provided. A braider **800** is provided. The braider **800** is adapted to position and provide overwrapping **805** of the pressure vessel **10** with the braiding material **795**. A binder spraying mechanism **810** is provided. The spraying mechanism **810** comprises a binder tank **815**, a binder spray head **820** and binder material **825**.

(31) In yet a further variant of the apparatus for fabricating a cellular reservoir flexible pressure vessel **10**, as shown in **Figure 26**, a high-strength reinforcing ribbon **830** is provided.

An automated reinforcing ribbon winding machine **835** is provided. The winding machine **835** comprises of a reinforcing ribbon spool **840** and an auto layout ribbon head **841**. A binder spraying mechanism **810** is provided. The spraying mechanism **810** comprises a binder tank **815**, a binder spray head **820** and binder material **825**.

(32) In still a further variant of the apparatus for fabricating a cellular reservoir flexible pressure vessel **10**, as shown in **Figure 27**, means **850** are provided for pulling a series of high tensile strength core wires **855** through orifices **105** in receptacles **55** in the end caps **45, 50** to a passageway **85** in the end caps **45, 50**. Means **286** are provided for injecting sintactic foam **270** through an opening **285** in the end caps **45, 50**. Means **880** are provided for attaching a sealing plug **290** to the opening **285**. Means **890** are provided for removing the core wires **855** from the end caps **45, 50**. When the core wires **855** are removed from the end caps **45, 50**, a series of canals **275** will be formed in the sintactic foam **270** connecting orifices **105** in receptacles **55** in the end caps **45, 50** to the passageway **85**.

(33) In yet a further variant of the apparatus for fabricating a cellular reservoir flexible pressure vessel **10**, as shown in **Figure 28**, means **900** are provided for attaching a series of flexible microtubes **291** to orifices **105** in receptacles **55** in the end caps **45, 50** to a passageway **85** in the end caps **45, 50**. Means **286** are provided for injecting sintactic foam **270** through an opening **285** in the end caps **45, 50**. Means **880** are provided for attaching a sealing plug **290** to the opening **285**. Means **890** are provided for removing the core wires **855** from the end caps **45, 50**. When the microtubes **291** are connected to the passageway **85**, the pressure vessel **10** will provide an ultra clean environment for either liquids or gasses.

(34) In still a further variant of the apparatus for fabricating a cellular reservoir flexible pressure vessel **10**, as shown in **Figures 18B, 18C, 18D, 18E, 29 and 29A**, means **930** are provided for forming a concave receptacle **485** having a shape selected from the group comprising: conical **490**, dome-shaped **495**, ellipsoid **500** and stair-stepped **505**.

(35) In a variant, as shown in **Figure 30**, means **960** are provided for forming the first **35** and second **40** ends of each of the flexible tubes **15** to fit sealably into the receptacles **55**.

(36) In yet a further variant of the apparatus for fabricating a cellular reservoir flexible pressure vessel **10**, as shown in **Figure 31** and **32**, means **940** are provided for forming upper **510** and lower **515** reinforcing panels. The reinforcing panels **510, 515** are formed of high-strength woven material **520** and are shaped as a form **525** to cover at least half of a surface area **526** of the pressure vessel **10** with extensions **530** projecting from a perimeter **535** of the form **525**. Means **531** are provided for adhering the reinforcing panels **510, 515** to the outer surface **536** of the pressure vessel **10**, thereby increasing the pressure handling capability of the pressure vessel **10**.

(37) In a variant, as shown in **Figure 32**, the method of adhesion is selected from the group comprising: high-strength adhesive, sonic welding and RF welding.

(38) In a another variant, the woven material **520** is prepregnated with either adhesive or laminating material and subjected to heat and pressure.

(53) In yet another variant, as shown in **Figures 33** and **34**, the cellular reservoir flexible pressure vessel **10**, has a first pressure relief device **1400**. The first pressure relief device **1400** is located on an inner surface **1405** of either the first **45** or second **50** end caps and includes a reduction in thickness **1406** of the end cap **45, 50** at a predetermined location

1410. When the pressure vessel **10** is subjected to an overpressure condition, it will fail at the predetermined location **1410**.

(54) In still another variant, as shown in **Figures 33** and **34**, the first pressure relief device **1400** has an indentation **1415** in the inner surface **1405** of either the first **45** or second **50** end caps. The indentation **1415** has side walls **1420** angled inwardly from the inner surface **1405**.

(55) In still a further variant, as shown in **Figures 36, 37** and **42**, the cellular reservoir flexible pressure vessel **10** has a second pressure relief device **1425**. The second pressure relief device **1425** is located on an outer surface **536** of the flexible pressure vessel **10** and has at least one projecting member **1435**. The projecting member **1435** is sized and shaped to penetrate the high-strength braiding material **295** at a predetermined location **1410**. When the high-strength braiding material **295** is penetrated by the projecting member **1435** and the flexible pressure vessel **10** is subjected to an overpressure condition, the vessel **10** will fail at the predetermined location **1410**.

(56) In an additional variant, as shown in **Figures 38** and **39**, the projecting member **1435** is removably attached to the outer surface **536** of the flexible pressure vessel **10**.

(57) In another variant, as shown in **Figures 36, 37** and **42**, the cellular reservoir flexible pressure vessel **10** has a second pressure relief device **1425**. The second pressure relief device **1425** is located on an outer surface **536** of the flexible pressure vessel **10** and has at least one projecting member **1435**. The projecting member **1435** is sized and shaped to penetrate the high-strength material **306** at a predetermined location **1410**. When the high-strength material **306** is penetrated by the projecting member **1435** and the flexible pressure

vessel **10** is subjected to an overpressure condition, the vessel **10** will fail at the predetermined location **1410**.

(58) In a further variant, as shown in **Figures 38** and **39**, the projecting member **1435** is removably attached to the outer surface **536** of the flexible pressure vessel **10**.

(59) In still a further variant, as shown in **Figures 36** and **41**, the cellular reservoir flexible pressure vessel **10** has a second pressure relief device **1425**. The second pressure relief device **1425** is located on an outer surface **536** of the flexible pressure vessel **10** and has at least one projecting member **1435**. The projecting member **1435** is sized and shaped to penetrate either the first **310** or second **335** flexible blankets at a predetermined location **1410**. When either the first **310** or second **335** flexible blanket is penetrated by the projecting member **1435** and the flexible pressure vessel **10** is subjected to an overpressure condition, the vessel **10** will fail at the predetermined location **1410**.

(60) In another variant of the invention, as shown in **Figures 38** and **39**, the projecting member **1435** is removably attached to the outer surface **536** of the flexible pressure vessel **10**.

(61) In an additional variant of the invention, as shown in **Figures 36, 41** and **42**, the ovoid flexible pressure vessel **10** has a second pressure relief device **1425**. The second pressure relief device **1425** is located on the outer surface **536** of the flexible pressure vessel **10** and has at least one projecting member **1435**. The projecting member **1435** is sized and shaped to penetrate either the upper **510** or lower **515** reinforcing panels at a predetermined location **1410**. When either the upper **510** or lower **515** reinforcing panel is penetrated by the projecting member **1435** and the flexible pressure vessel **10** is subjected to an overpressure condition, the vessel **10** will fail at the predetermined location **1410**.

(62) In a further variant of the invention, as shown in **Figures 38** and **39**, the projecting member **1435** is removably attached to the outer surface **536** of the flexible pressure vessel **10**.

(63) In still a further variant of the invention, as shown in **Figures 43** and **44**, the cellular reservoir flexible pressure vessel **10** has a third pressure relief device **990**. The third pressure relief device **990** has a weakened section **995** of the passageway **85**. When the flexible pressure vessel **10** is subjected to an overpressure condition, the flexible pressure vessel **10** will fail at the weakened section **995** of the passageway **85**.

(64) In another variant, as shown in **Figures 43** and **44**, the weakened section **995** of the passageway **85** has a smaller cross-sectional area **1000** than a balance of the passageway **85**.

(65) In an additional variant, as shown in **Figure 49**, the cellular reservoir flexible pressure vessel **10** has high-strength braiding material **295** wound about the passageway **85**, thereby providing additional resistance to pressure for the flexible pressure vessel **10**.

(66) In a further variant, as shown in **Figure 50**, the cellular reservoir flexible pressure vessel **10** has a fourth pressure relief device **1015**. The fourth pressure relief device **1015** has either a weakening or an absence of high-strength braiding material **295** at a predetermined location **1410** along the passageway **85**. When the flexible pressure vessel **10** is subjected to an overpressure condition, the flexible pressure vessel **10** will fail at the predetermined location **1410** along the passageway **85**.

(67) In still a further variant, as shown in **Figure 51**, the cellular reservoir flexible pressure vessel **10** has hoop winding **305** about the passageway **85**, thereby providing additional resistance to pressure to the flexible pressure vessel **10**.

(68) In another variant of the invention, as shown in **Figure 52**, the cellular reservoir flexible pressure vessel **10** has a fifth pressure relief device **1030**. The fifth pressure relief device **1030** has either a weakening or an absence of hoop winding **305** at a predetermined location **1410** along the passageway **85**. When the flexible pressure vessel **10** is subjected to an overpressure condition, the pressure vessel **10** will fail at the predetermined location **1410** along the passageway **85**.

(69) In an additional variant, as shown in **Figure 42**, the cellular reservoir flexible pressure vessel **10** has either a weakening or a spreading of fibers **1040** in the high-strength braiding material **295** at a predetermined location **1410**. The predetermined location **1410** is above an outer surface **536** of the pressure vessel **10**. When the high-strength braiding material **295** has the fibers **1040** weakened or spread in the predetermined location **1410** and the pressure vessel **10** is subjected to an overpressure condition, the pressure vessel **10** will fail at the predetermined location **1410**.

(70) In a further variant, as shown in **Figure 42**, the cellular reservoir flexible pressure vessel **10** has either a weakening or a spreading of fibers **1055** in the high-strength material **306** at a predetermined location **1410**. The predetermined location **1410** is above an outer surface **536** of the pressure vessel **10**. When the high-strength material **306** has the fibers **1055** weakened or spread in the predetermined location **1410** and the pressure vessel **10** is

subjected to an overpressure condition, the pressure vessel **10** will fail at the predetermined location **1410**.

(71) In still a further variant, as shown in **Figures 47** and **48**, the cellular reservoir flexible pressure vessel **10** has either a weakening or a spreading of fibers **1055** in either the first flexible blanket **310** or the second flexible blanket **335** at a predetermined location **1410**. The predetermined location **1410** is above an outer surface **536** of the pressure vessel **10**. When either of the first flexible blanket **310** and the second flexible blanket **335** has the fibers **1055** weakened or spread in the predetermined location **1410** and the pressure vessel **10** is subjected to an overpressure condition, the pressure vessel **10** will fail at the predetermined location **1410**.

(72) In another variant of the invention, as shown in **Figure 41**, the cellular reservoir flexible pressure vessel **10** has either a weakening or a spreading of fibers **1055** in either the upper **510** or lower **515** reinforcing panels at a predetermined location **1410**. The predetermined location **1410** is above the outer surface **536** of the pressure vessel **10**. When either of the upper **510** or lower **515** reinforcing panels has the fibers **1040** weakened or spread in the predetermined location **1410** and the pressure vessel **10** is subjected to an overpressure condition, the pressure vessel **10** will fail at the predetermined location **1410**.

(73) In an additional variant of the invention, as shown in **Figures 45** and **46**, the connection **88** to either a passageway **85** of another pressure vessel **10** or a valve **90** further has a capillary tube **1100**. The capillary tube **1100** has a proximate end **1105** and a distal end **1110** and is formed of resilient material **1115** and sized and shaped to fit slidably within the passageway **85**. High-strength braiding material is provided **295**. The braiding material **295**

is located about the capillary tube **1100** and extends along the capillary tube **1100** to within a first predetermined distance **1125** from the proximate end **1105**. The proximate end **1105** of the braiding **295** covered capillary tube **1100** is inserted into the passageway **85** and is either radio frequency welded or secured with adhesive to it. When the proximate end **1105** of the capillary tube **1100** is either welded or secured with adhesive within the passageway **85**, it will be permanently attached to it.

(74) In a further variant of the invention, as shown in **Figures 40** and **40A**, an apparatus **1130** for modifying flexible blanket material **1145** is provided. The apparatus **1130** has means **1135** for supporting a supply roll **1140** of flexible blanket material **1145**. Means **1150** for moving the flexible blanket material **1145** from the supply roll **1140** to a work area **1155** is provided. Means **1160** for tensioning the flexible blanket material **1145** in the work area **1155** is also provided. At least one separating member **1165** is provided. The separating member **1165** is sized and shaped to penetrate and separate fibers **1055** of the flexible blanket material **1145** is further provided.

Means **1175** for moving the separating member **1165** into the tensioned flexible blanket material **1145** at a predetermined location **1180** in the material **1145**, thereby either weakening and separating the fibers **1055** is provided. Means **1185** for retracting the separating member **1165** from the tensioned flexible blanket material **1145** is provided. Means **1190** for moving the flexible blanket material **1145** from the work area **1155** to a storage area **1195** is provided. The flexible blanket material **1145** will have either a weakened or separated fibers **1055** in the predetermined location **1180** prior to application to the pressure vessel **10**.

(75) In still a further variant of the invention, as shown in **Figures 40** and **40A**, an apparatus **1130** for modifying reinforcing panel material **1215** is provided. The apparatus **1130** has means **1135** for supporting a supply roll **1210** of reinforcing panel material **1215**. Means **1150** for moving the reinforcing panel material **1215** from the supply roll **1210** to a work area **1155** is provided. Means **1160** for tensioning the reinforcing panel material **1215** in the work area **1155** is provided. At least one separating member **1165** is provided. The separating member **1165** is sized and shaped to penetrate and separate fibers **1055** of the reinforcing panel material **1215**. Means **1175** for moving the separating member **1165** into the tensioned reinforcing panel material **1145** at a predetermined location **1180** in the material **1215**, thereby either weakening or separating the fibers **1055** is provided. Means **1185** for retracting the separating member **1165** from the tensioned reinforcing panel material **1215** is provided. Means **1190** for moving the reinforcing panel material **1215** from the work area **1155** to a storage area **1195** is provided. The reinforcing panel material **1215** will have either weakened or separated fibers **1055** in the predetermined location **1180** prior to application to the pressure vessel **10**.